E/CONF.39/A/59
2 Oct.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.3.3

South Africa

GROUND-WATER PROSPECTING METHODS USED IN THE REPUBLIC OF SOUTH AFRICA

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A.3.3.

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1. Introduction

(a) The utilization of the semi-arid and arid 65% of the Republic of South Africa depends very largely on development of underground water and, even in the relatively well-watered parts, supplementary underground supplies are usually essential for efficient farming.

(b) Thick deposits of sand and gravel, and permeable sandstone, the principal aquifers in countries such as the U.S.A., are scarce in South Africa and most of the c.500,000 bore-holes are in bedrock. With the exception of some sandstone, the rocks have virtually no inherent permeability; the aquifers are secondary in origin and have formed by fracturing, weathering and solution. They are often narrow zones which are difficult to locate under soil cover. The percentage of weak and dry bore-holes is thus very high:

Percentage of bore-holes	Initial yield exceeded	
2	5000 imp.g./hr	(22.5 cu.m./hr)
11	2000 " "	(9.0 " ")
21	1000 " "	(4.5 " ")
31	500 " "	(2.25 " ")
42	200 " "	(0.9 " ")
50	100 " "	(0.45 " ")

As the vast majority of the holes are drilled for stock watering and for domestic purposes on farms, a successful bore-hole is generally taken as one with a yield exceeding 100 g. (0.45 cu.m.)/hr.

(c) Water-divining has been, and still is to some extent, used for locating drilling sites - usually with very disappointing results. Scientific methods developed by the Geological Survey for South African conditions have proved valuable in considerably reducing the number of failures and the costs of developing usable supplies. Savings of up to 50% have been effected (2,7,9,11).

2. Preliminary Studies of Geohydrological Data

Logs of the c.85,000 bore-holes drilled by government drills and files of water analyses provide useful indications as to the nature of the aquifers, depth to water, and quantity and quality to be expected (8)

3. Indications from Vegetation

(a) Dykes, which are often flanked by water-bearing zones, are generally marked by lines of trees and more luxuriant bushes (par.5.b.(i)), so also are some crush-zones and major joints.

(b) On the Transvaal highveld a grass (Fingerhuthia sesleriaeformis) seems to flourish only where the underlying rocks are permeable and the water-table is very near the surface. Using it as an indicator, successful bore-holes have been drilled in sedimentary rocks within short distances of failures. It is believed that the very shallow water-table required by this grass is maintained by ground-water flow from higher-lying areas.

(c) The Karroo amygdaloidal basalt in the central Transvaal tends to weather to only shallow depths. Locally it is cut by vertical fissure-zones that are generally hidden by soil. During the dry winter months the soil dries out, and before the first rains very little water is available to the indigenous plants, save deep-rooted ones situated over fissure-zones that form aquifers. In early spring, lines of green trees demarcate these aquifers and very successful boring sites have been selected.

4. Geological Surveys

(a) Geological reconnaissance, using air photographs which cover almost the entire country, is useful for tracing dykes, zones of fracturing and other favourable structures. In the field, the topography is noted in relation to the disposition of the rocks and their dips, if layered, to obtain an idea whether recharge of aquifers is likely under the local conditions of climate, soil and vegetation. In some cases it is possible to deduce the hydrological properties of some rocks at depth and select sites (8). Examples follow:

(i) In parts of Zululand, the Karroo basalt is cut by dykes of volcanic breccia that form conspicuous bushy ridges. About 60% of the bore-holes drilled in or next to these dykes proved successful as compared with 28% success on non-geological/geophysical sites (11).

(ii) If the contacts of Karroo dolerite dykes cutting sedimentary rocks are well exposed, drilling sites may be selected so as to penetrate the contact-zones below the water-table (par.5.b.). Some of the narrow dykes are themselves extensively fractured and very successful bore-holes have been drilled in them (9).

(iii) Fault-zones have been found in cliffs and cuttings and projected to soil-covered areas where sites were required. Some have yielded fairly large supplies.

(b) The geohydrological section, Fig.I, was prepared by geological mapping and plotting the logs of a row of experimental bore-holes. Five aquifers, representative of some of the more important types in the country, were delineated. Nos.1 and 4 are formed by weathered diabase and are relatively shallow (par.5.c.(iv)); Nos.2 and 3 are shales that have acquired fairly high permeabilities through jointing and cleavage and extend much deeper. No.5 is the fracture-zone of a vertical fault; it is recharged by rain falling on the bare quartzite face of the ridge immediately to the south and also by influent seepage from a river further east. The underground water overflows from No.5 into No.4 and from there into the one with the largest storage, No.3, which has been fully developed for spray irrigation. No.2 is recharged by seepage from the adjoining aquicludes at about 9 cu.m./hr. Such experimental drilling facilitates the selection of successful boring sites.

5. Geophysical Surveys

(a) Geophysical surveys, using sometimes more than one method, often have to be employed to supplement geological ones and are essential when the potential aquifers are hidden by soil or alluvium.

(b) Surveys of the vertical magnetic field have proved valuable for tracing dykes and the margins of intrusive sheets.

(i) The generally almost flat-lying sandstone, mudstone and shale of the Karroo System (Carboniferous to Triassic), which covers nearly half the country, usually have very low permeabilities and specific yields. On some farms over a hundred bore-holes have been drilled in them without striking more than a few gallons per hour. It was found that narrow, indurated zones of intense jointing along the margins of many of the numerous dolerite intrusions form aquifers that are recharged by percolation from adjacent aquicludes.

(ii) The dolerite dykes are generally 5 to 10 m. wide and the indurated contact-zones seldom exceed 0.5 m. Bore-holes must thus be sited with great precision to strike such narrow aquifers at optimum depths. Fortunately most of the dykes are magnetic and a technique of interpretation of their magnetic anomalies has been developed to locate their margins accurately even under deep soil cover (4). Fig.II is a typical example. Eighteen bore-holes had been drilled near the homestead on this farm, but all were failures. A long magnetometric traverse revealed the presence of a dyke which was traced by a series of short traverses. Both positive and negative peaks occur, which mark the contacts of the hidden dyke. Under deep soil a dyke generally gives rise to only a single, rather wide anomaly due to superposition of anomalies from individual poles; however, if sufficient traverses are made, some will show anomalies with two or more peaks (6). The two parallel lines joining the outer peaks approximate within a metre to the contacts of the dyke. On the farm in question the indurated zone was first just missed; the machine was moved 1 m. nearer the contact - a supply of 1800 g. (8.2 cu.m.)/hr was then obtained.

(iii) Unfortunately it has not proved possible to determine the dips of the dykes from their magnetic anomalies, which are almost entirely due to remanent magnetization (4). Dip indications may be obtained from their traces if they cross valleys, and from logs of existing bore-holes. Usually it is necessary to drill trial holes to establish the attitudes of a dyke so that bore-holes may be sited to strike one or other of the contact-zones below the water-table. Near-surface tilting of some dykes has caused difficulties (4).

(iv) In areas underlain by dolerite sheets, the water is generally found in the upper and/or lower contact-zones, if not too deeply buried. The lower is usually the better aquifer, especially fairly near the denuded edges of the intrusions (9). In general, conditions are favourable where the contact-zones dip and are unfavourable where they are horizontal.

(c) Electrical resistivity surveys are mainly used for locating basins and closed troughs of weathering in igneous rocks, which cover almost a third of the country (6).

(i) It has been found that it is much faster to use an alternating current or reversed direct current, with steel electrodes, than direct current with non-polarising electrodes. The Wenner configuration (4 electrodes equally spaced in a straight line) is usually used, with a 5-man crew. Due to the difficulty of getting current into dry

ground, it is often necessary to drive the electrodes to depths of a metre or more. Their extraction is often difficult and time-wasting. A combined electrode and hammer was thus recently developed. It consists of a steel electrode 1½ m. long with a collar at its upper end. A tubular hammer is fitted and a sleeve welded on to the inside of its lower end to prevent the electrode falling out. It is easily driven by downward strokes of the hammer and is readily extracted by a few upward jars.

(ii) Depth-probe traverses are generally resorted to. To avoid excessive lateral effects, the electrode spreads are orientated, if possible, parallel to the strike of layered rocks and dykes. The depths to the contact between weathered and solid rock are empirically determined in the field from apparent resistivity/electrode separation curves (3,6). When deep weathering is found, the traverse is expanded into a grid. Resistivity sections are drawn through the depth-probe centres and lateral effects eliminated (3). A geohydrological interpretation is then made.

(iii) Fig.III shows part of a farm on Bushveld granite where a basin of weathering, with a maximum depth of 35 m., was found. Note that the subcontours of the basin are not related to the surface contours. This is nearly always the case; in some granitic areas the deepest weathering is on broad ridges between water-courses, and boring sites are much more successful there than in the valleys.

(iv) In basins and troughs of weathering, the main supplies of water are generally struck in the irregular partially weathered and broken zone just below the weathered rock. For this reason drilling should continue to a depth of as much as 15 m. below the depth of weathering deduced from depth-probes (2). A "broken" zone is essential for successful bore-holes in basic igneous rocks, which weather to clayey materials with very low permeabilities. Unfortunately its presence cannot be established by electrical resistivity surveys and failures have been proved, by electric logging, to be due to its absence in basins or sections of basins. The yield of a bore-hole is affected by the slope of the floor of the basin as steeper pressure gradients can develop under pumping in thin, dipping aquifers than in horizontal ones (3,6).

(v) The electrical resistivity method is also used to determine the thickness of sedimentary rocks overlying dolerite sheets (par.5.b.(iv)) and to trace old river channels filled with water-bearing sands and gravels. Resistivity logging is extensively used to determine the actual depths, thicknesses and resistivities of aquifers and, for bore-holes in progress, to indicate whether deepening is justified. Such logging eliminates much fruitless drilling.

(d) The electromagnetic method is used for locating fissures under soil cover in rocks that are not weathered sufficiently deeply to form basins, and in which fractures are not associated with magnetic dykes and also do not show on air photographs. The method fails, however, if the conductivity of the fissured zone is the same as the country-rock.

(i) An alternating current of audio-frequency is introduced conductively into the ground (1). Measurements of the tangential component of the horizontal electromagnetic field are taken on concentric circles around the current source. Peaks indicate current concentrations due to narrow conducting zones which are generally water-filled. If such peaks are obtained on the circles, they are further traced by

measurements on short arcs (5). In open country 20 hectares can be covered per day by a 6-man crew. Supplies of up to 50 cu.m./hr have been obtained.

(ii) The example (Fig.IV) is a site on Archaean granite. A prominent quartz vein had been used for siting a bore-hole (No.1), but only a small supply was struck and the second bore-hole away from the vein was dry. An electromagnetic survey disclosed an inclined fracture-zone up to 60 m. from the quartz vein. Sites selected to strike it at optimum depths gave satisfactory yields. The fissure-zone apparently branches off from the quartz vein, which is for the most part impermeable. In the case of such inclined zones, the electromagnetic peaks are displaced from the sub-outcrop in the direction of dip. In general the depth below a peak to the fissure is about twice the thickness of the overburden (5).

(e) Seismic and gravity surveys have been used recently with success to determine the configuration of an artesian basin.

The Geological Survey's draughtsmen are thanked for preparing the figures.

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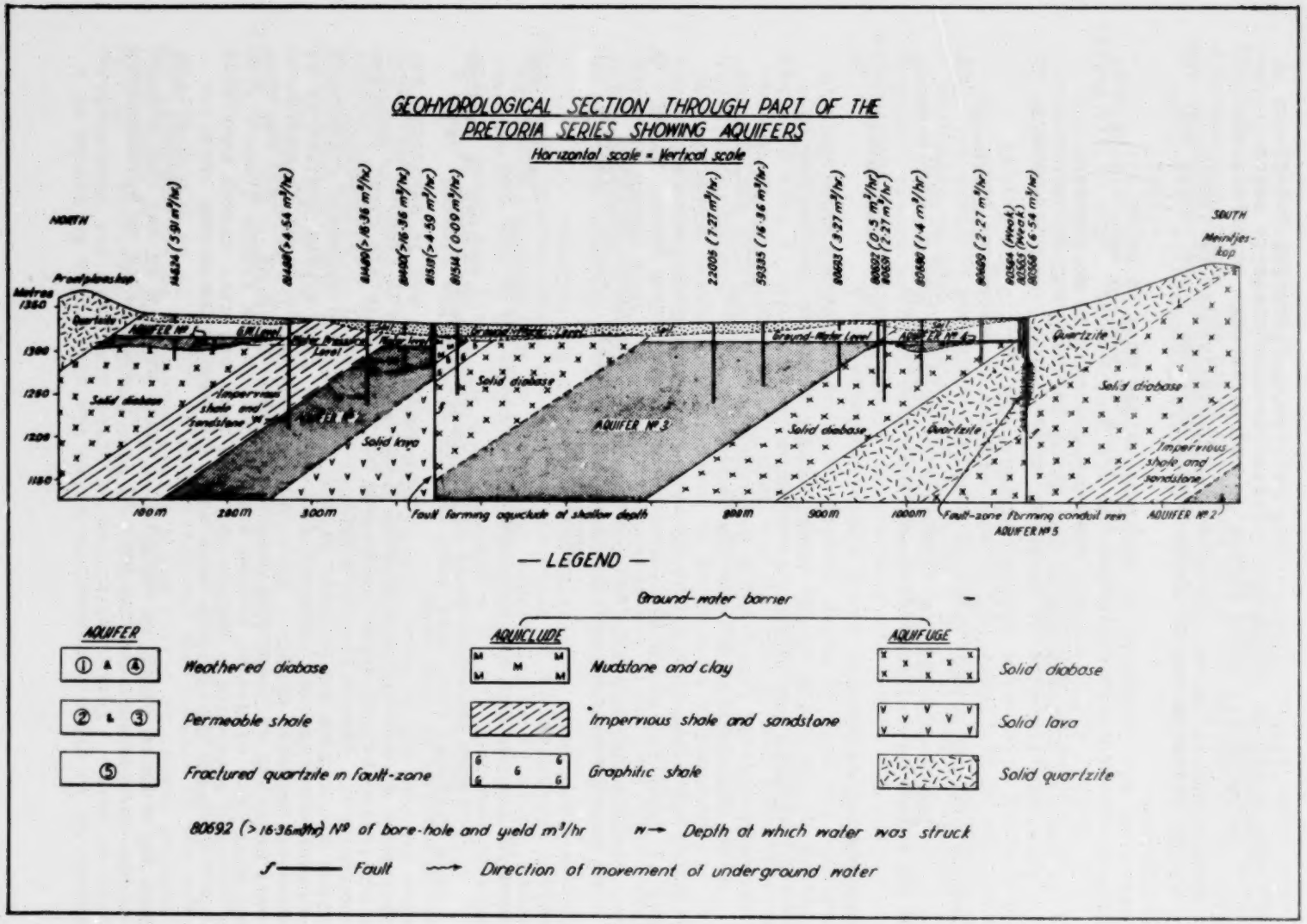
GEOHYDROLOGICAL SECTION THROUGH PART OF THE PRETORIA SERIES SHOWING AQUIFERS
Horizontal scale = Vertical scale
NORTH
SOUTH
Meintjes-kop
Metres
1350
1300
1250
1200
1150
Quartzite
Solid diabase
Impervious shale and sandstone
Solid lava
Ground-Water Level
AQUIFER No 3
AQUIFER No 4
AQUIFER No 5
AQUIFER No 2
190m
200m
300m
800m
900m
1000m
Fault forming aquiclude at shallow depth
Fault-zone forming conduit rein
— LEGEND —
Ground-water barrier
AQUIFER
AQUICLUDE
AQUIFUGE
Weathered diabase
Permeable shale
Fractured quartzite in fault-zone
Mudstone and clay
Impervious shale and sandstone
Graphitic shale
Solid diabase
Solid lava
Solid quartzite
80692 (>16·36m³/hr) No of bore-hole and yield m³/hr
Depth at which water was struck
Fault
Direction of movement of underground water

Figure I

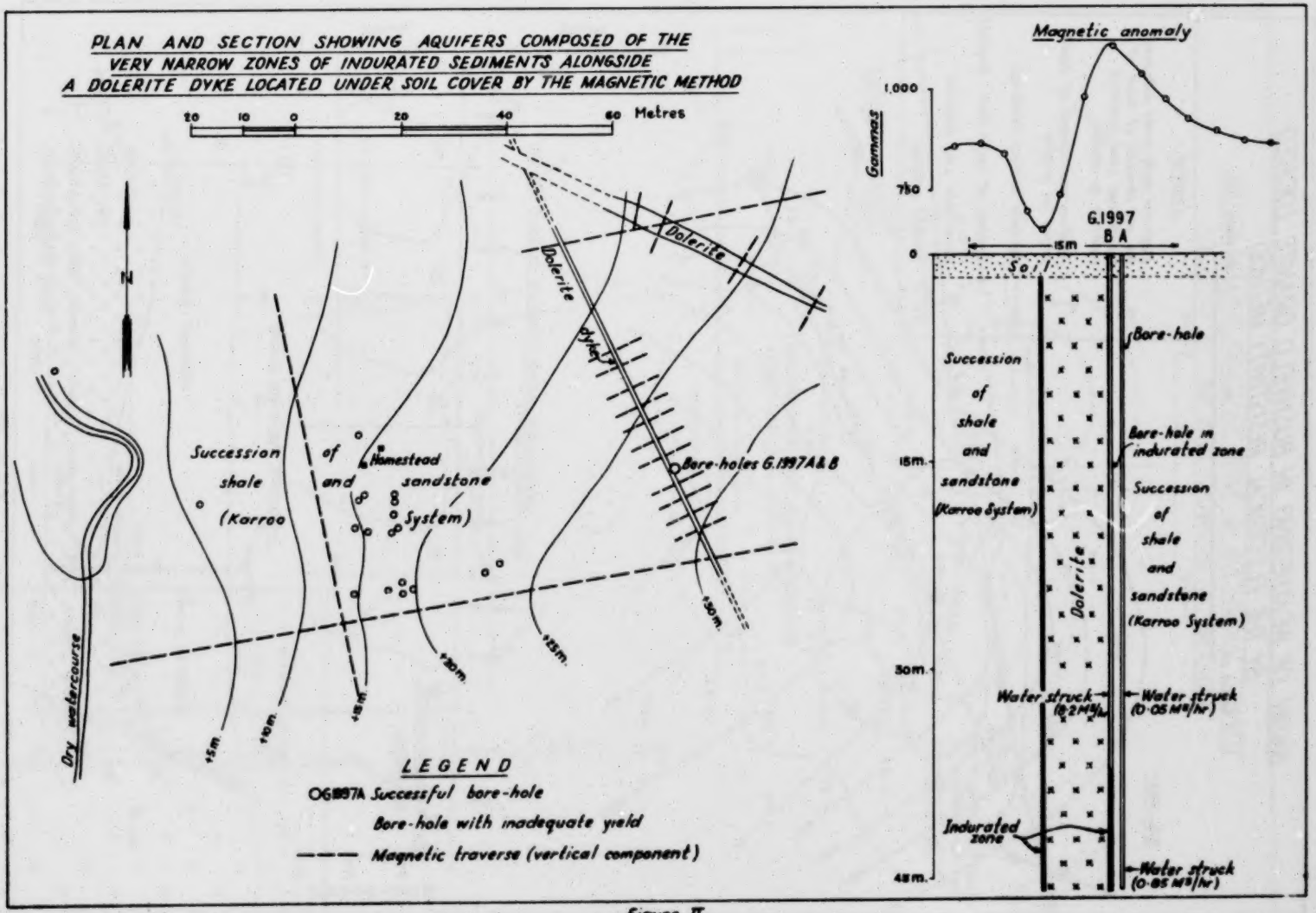
PLAN AND SECTION SHOWING AQUIFERS COMPOSED OF THE VERY NARROW ZONES OF INDURATED SEDIMENTS ALONGSIDE A DOLERITE DYKE LOCATED UNDER SOIL COVER BY THE MAGNETIC METHOD
20 10 0 20 40 60 Metres
N
Dolerite
Dolerite dyke
Succession of shale and sandstone (Karroo System)
Homestead
Bore-holes G.1997A & B
Dry watercourse
+15m
+10m
+15m
+20m
+25m
+30m
LEGEND
G.1997A Successful bore-hole
Bore-hole with inadequate yield
Magnetic traverse (vertical component)
Magnetic anomaly
Gammas
1,000
750
0
G.1997
B A
15m
Soil
Bore-hole
Succession of shale and sandstone (Karroo System)
Bore-hole in indurated zone
Succession of shale and sandstone (Karroo System)
15m.
Dolerite
30m.
Water struck (0·2 M³/hr)
Water struck (0·05 M³/hr)
Indurated zone
Water struck (0·05 M³/hr)
45m.

Figure II

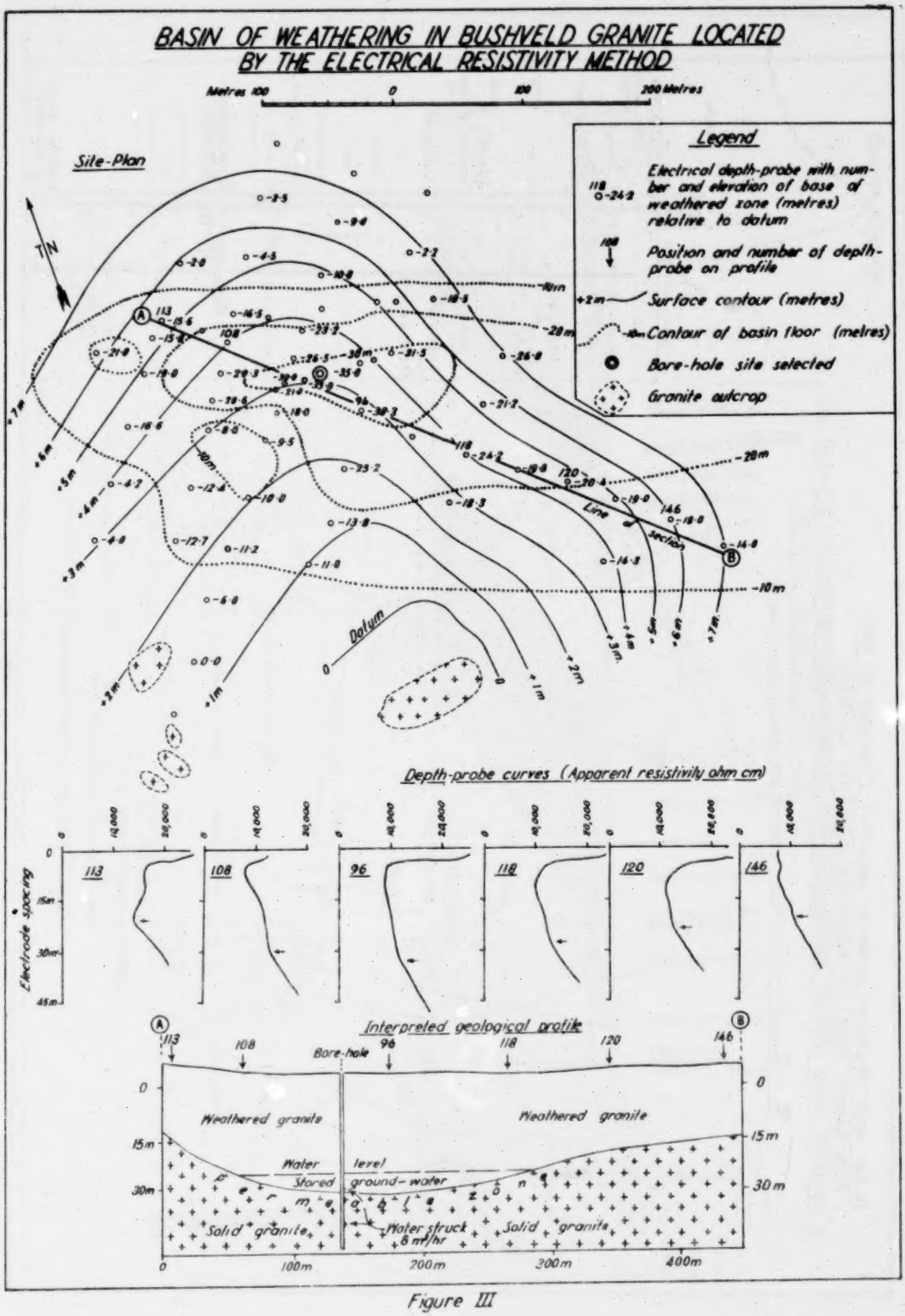
BASIN OF WEATHERING IN BUSHVELD GRANITE LOCATED BY THE ELECTRICAL RESISTIVITY METHOD
Metres 100 0 100 200 Metres
Site-Plan
TN
Legend
Electrical depth-probe with number and elevation of base of weathered zone (metres) relative to datum
Position and number of depth-probe on profile
Surface contour (metres)
Contour of basin floor (metres)
Bore-hole site selected
Granite outcrop
Datum
Line of section
Depth-probe curves (Apparent resistivity ohm cm)
Electrode spacing
113
108
96
118
120
146
Interpreted geological profile
Bore-hole
Weathered granite
Water level
Stored ground-water
Solid granite
Water struck 6 m³/hr
100m
200m
300m
400m

Figure III

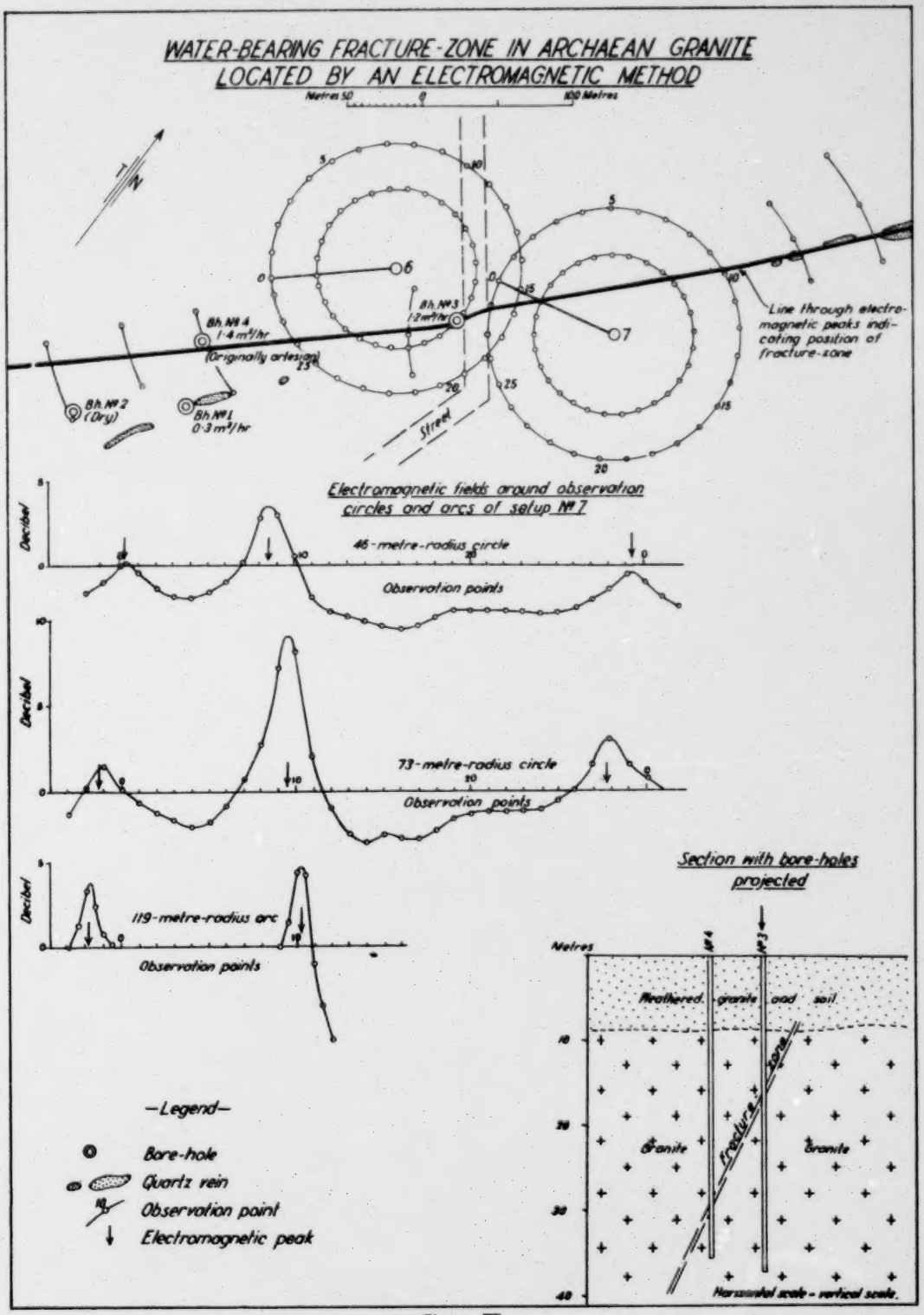
WATER-BEARING FRACTURE-ZONE IN ARCHAEAN GRANITE
LOCATED BY AN ELECTROMAGNETIC METHOD
Metres 50 0 100 Metres
N
Bh. No 4
1·4 m³/hr
(Originally artesian)
Bh. No 3
1·2 m³/hr
Bh. No 2
(Dry)
Bh. No 1
0·3 m³/hr
Street
6
7
Line through electro-magnetic peaks indicating position of fracture-zone
Electromagnetic fields around observation circles and arcs of setup No 7
Decibel
46-metre-radius circle
Observation points
73-metre-radius circle
Observation points
119-metre-radius arc
Observation points
Section with bore-holes projected
Metres
Weathered granite and soil
fracture zone
Granite
Granite
Horizontal scale = vertical scale.
—Legend—
Bore-hole
Quartz vein
Observation point
Electromagnetic peak

Figure IV

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